

A Systematic Review on Industry 4.0 Maturity Metrics in the Manaus Free Trade Zone

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Keywords— Industry 4.0, Innovation, Maturity Model, Pro-Know-C, Systematic Review.

Abstract— The term industry 4.0 has been widely used as a symbol of the fourth industrial revolution, and in this context, the adequacy of companies to the set of digital technologies has become a meaning of competitiveness or leadership maintenance, with research, development, and innovation as the basic prerequisite for the company or its partners to materialize the cited improvement. In this scenario, measuring the maturity of companies is the main requirement for establishing strategies for the digital advancement of industry in the form of private actions or government public policies. With the purpose to obtain the state-of-the-art regarding the measurement of maturity under the metrics of industry 4.0 and its relation with innovation, this work used the Knowledge Development Process - Constructivist (ProKnow-C) tool, which enabled the construction of a bibliographic portfolio composed of 27 papers published in Journals and 4 publications of actors involved in the industry digital transformation. Although the richness of the selected literature concerning maturity models, it was acknowledged a scientific gap concerning its relationship with innovation investments involving tax benefits from the government, which is one of the main objectives of this work.

I. INTRODUCTION

The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

Considered by the literature as the fourth industrial revolution, industry 4.0 was inserted in the manufacturing historical context started in the 18th century with the invention of the steam engine, followed by the use of electric energy for mass production and, later, industrial automation, culminating in the current generation of cyber-physical systems of autonomous and intelligent production involving a great variety of other technologies (Geissbauer et al. 2016, Schuh et al. 2020, Yao et al. 2019).

The possibility of integrating processes both vertically and horizontally allows not only production to benefit from technologies related to industry 4.0, but all relations involving supply chain actors and the respective processes.

Understanding that it is of absolute importance for the positioning of Brazilian production value chains, more specifically from the Manaus Industrial Pole (MIP), the Brazilian Government has made efforts towards the implementation of public policies to encourage the advance of production in the direction of digital transformation.

An example of this is the publication of Ordinance No. 2,091, of December 17, 2018 (Brazil 2018), from the then Ministry of Industry, Foreign Trade and Services (assignment currently assumed by the Ministry of Economy), which provides for the methodology to be adopted in investments in research, development, and innovation (RD&I) aimed at industry 4.0 in the Manaus Free Trade Zone, which, in short, defines that projects must promote digital evolution under metrics based on the system developed by the German Association of Science and Engineering (ACATECH) applied under a diagnosis

of a productive process in which a project is to be executed.

Such investments are foreseen within a broader context treated by Federal Law No. 8,387, of December 30, 1991 (Brazil 1991), also locally known as the Informatics Law (IL), which establishes an obligation for application in RD&I to all companies that manufacture computer goods at MIP that take advantage of taxes benefits in the purchase of imported production supplies, as well as in the sale of manufactured computer goods.

Facing the aforementioned initiatives, there are movements involving various actors of the regional ecosystem, which include the companies that receive benefits from the mentioned law, the academy, institutes of science and technology (IST), startups, among others (Brazil 1991), whose activities have effects that are not yet completely transparent from the socioeconomic point of view, what can be proved by the lack of scientific literature evidencing such results: the companies' capacities to insert themselves in the desired set of systems that makes industry 4.0 one of the ways to remain competitive and lead by the use of benefits provided by the law and its regulations.

From production development means and methods in the sense of industry 4.0, and bearing in mind that, as conceptualized by Zaoui and Souissi (2020) and Ercan and Samet (2020), measuring the maturity or readiness of companies is the basis for defining the roadmap to successfully achieve the digital transformation, this work aims, through a systematic review of the scientific literature, to reach the state-of-the-art in measuring the maturity (or readiness) of companies under the metrics of industry 4.0, relating results to the RD&I performed by them as an obligation under the Informatics Law.

Intending to scientifically strengthen the understanding of the theme, this work uses the Knowledge Development Process - Constructivist (ProKnow-C) methodology developed at the Multicriteria Methodologies Laboratory in Decision Support of the Federal University of Santa Catarina to solve a problem related to the abundance of information available in a research sources multitude that makes the researcher work increasingly complex to find the most appropriate references to the research being carried out (Ensslin et al. 2015, Ensslin, S. and Ensslin, L. 2014). Such a tool has been consolidated for obtaining a portfolio based on searches in the databases of journals to build a bibliographic reference centered on the topic from the researcher's point of view.

II. SCENARIO

Industry 4.0 and RD&I in Manaus Free Trade Zone

Initially used in Germany, the term "Industry 4.0" has become synonymous with the digital transformation of the means of production, focusing on making industrial plants hyper-connected, intelligent, and autonomous (Buhr 2015, Schuh et al. 2020, Wittenberg 2015) through the use of information and communication technologies (ICT) embedded in cyber-physical systems involving three paradigms: (i) the product, which must enter as part of the process, addressing itself which values should be added in terms of components and services; (ii) the machine, which must be autonomous, intelligent and connected; and (iii) operator, whose functions have to be completely flexible within the process, adapting to the challenges provided by the systems (Weyer et al. 2015).

According to GERMANY TRADE & INVEST-GTAI (2016) and Buhr (2015), such a change is not only made by companies but involves academia in professionals formation, governments in the elaboration of public policies, IST for the development of new technologies, among other actors.

In a study carried out worldwide by PwC, in which Brazil was inserted, it was identified that in 2016, only 9% of Brazilian companies were classified as having a high degree of processes digitalization, and the same research concluded that entrepreneurs, at the time, believed that this indicator would be at 72% in 2020 (Geissbauer et al. 2016).

In the same direction as the observation that Brazilian industrialization has faced challenges in the direction of digitalization, Federal Law no 8,387/1991 (Brazil 1991), which establishes an obligation to invest in RD&I to all TIC goods manufacturers that make use of the Manaus Free Trade Zone benefits the equivalent to 5% of the gross revenue earned on such products, minus taxes, returns and purchases of inputs also beneficiaries of the referred Law, must be compulsorily carried out annually within the geographic limits of the Western Amazon or the State of Amapa (SUFRAMA 2020, Brazil 1991),

The Federal Government of Brazil is represented in the aforementioned region by the Manaus Free Trade Zone Superintendence (SUFRAMA) which, among other activities aimed at regional development, has the role of monitoring the investments made under IL, which reached in 2018 R\$ 681.8 million (SUFRAMA 2020), as shown in Fig. 1, with the academy, IST or the eligible companies to use it (Brazil 1991).

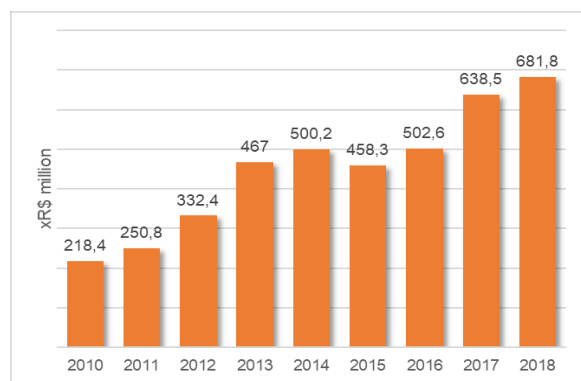


Fig. 1: Investment in RD&I in Manaus Free Trade Zone – Informatics Law (x R\$ million)

Within the theme of industry 4.0, there is also the regulation of two standards related to the IL: Ordinance No. 2,091, of December 17, 2018 (Brazil 2018), which deals with investments made by companies in their industrial parks to promote the digital gain on their processes; and CAPDA¹ Resolution No. 9, of October 29, 2019, which defines the “INDUSTRY 4.0 AND INDUSTRIAL MODERNIZATION” program as a priority in the area covered by SUFRAMA’s influence. (Brazil 2019).

Having verified the large volume of resources used for RD&I in a closed geographical area, concurrently with government actions in terms of public policies, it is expected that the companies holding this obligation are at least outlining the path for the implementation of the three paradigms proposed by Weyer et al. (2015), given that, according to Mihardjo et al. (2019), companies need to be innovative to bring to their processes the new digital age characterized by industry 4.0.

In this context, this work deals with the bibliographic survey for the scientific reference determination to reach the maturity (or readiness) measurement under the metrics of industry 4.0 that will be a subsidy to position the companies benefiting from IL in terms of digital transformation in their value chains.

III. METHODOLOGY

The present work is exploratory-descriptive research from the objectives, considering that it aims the literature finding to expand the knowledge on the subject, and selection procedures must be performed to determine the set to be used as a study reference (Silva and Menezes 2001).

¹ CAPDA: Committee for Research and Development Activities in the Amazon created by IL.

As for the approach, it is configured as a quantitative work since it will systematically identify the bibliographic portfolio on the topic obtained through the use of the Knowledge Development Process – Constructivist (ProKnow-C) methodology, given that, as mentioned by Ensslin et al. (2015), the tool works to provide the necessary knowledge to start the research that is intended to be carried out in a constructivist way through the process of data collection and analysis.

ProKnow-C as a system is divided into macro processes (Ensslin et al. 2015), two of which were carried out in this work, shown in Fig. 2 and detailed below:

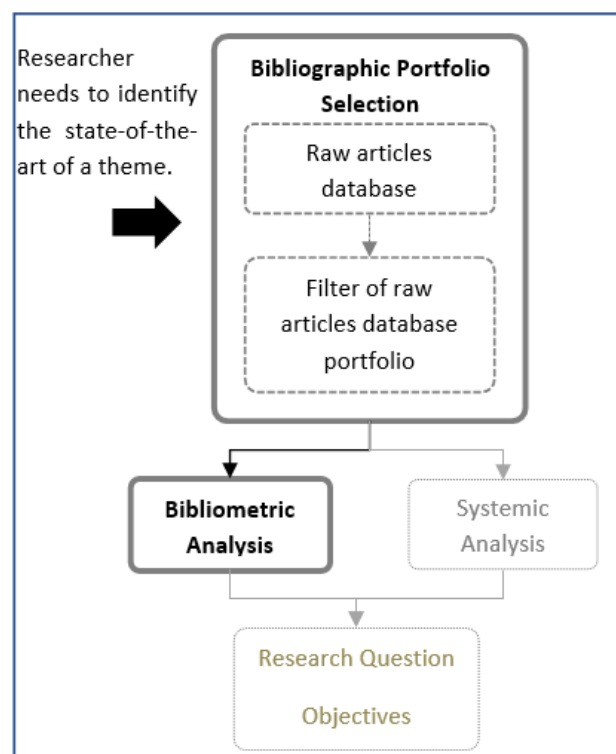


Fig. 2: ProKnow-C macro processes, emphasizing those used in this work

3.1. Construction of the Bibliographic Portfolio

It is about the selection of the set of publications that will compose the bibliographic portfolio which is presented in two stages: (i) the selection of the raw article database and (ii) the filter of the selected database based on the researched topic (Fig. 2).

3.1.1. Selection of raw articles database

The first step in the selection of the raw article database considers the research dimensions related to the theme, from which the keywords are determined (table 1). The defined dimensions take into account the core of the research, those are industry 4.0; model; maturity; and research and development.

Table 1: Dimensions and keywords definition

industry 4.0	model	maturity	R&D
“Industry 4.0”	Model	Maturity	R&D
“Smart Manufacturing”	Assessments	Readiness	“Research and Development”
“Digital Transformation”			Innovation
“Fourth Industrial Revolution”			
“4th Industrial Revolution”			

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

The keywords in Table 1 resulted in 60 combinations applied to the Journals portal of Coordination for the Improvement of Higher Education Personnel (CAPES)², resulting in publications available in 19 databases.

From the periodical bases selected by the CAPES portal, it was possible to merge the research as follows (table 2).

Table 2: Journals Bases result

BASE/COLLECTION	SOURCE BASE
Scopus (Elsevier)	Scopus Elsevier
Materials Science & Engineering Database	ProQuest
Advanced Technologies & Aerospace Database	ProQuest
Technology Research Database	ProQuest
Engineering Research Database	ProQuest
Mechanical & Transportation Engineering Abstracts	ProQuest
Computer and Information Systems Abstracts	ProQuest
Civil Engineering Abstracts	ProQuest

²CAPES Portal is available on: <https://www.periodicos.capes.gov.br/>

Materials Business File	ProQuest
Solid State and Superconductivity Abstracts	ProQuest
Aerospace Database	ProQuest
ANTE: Abstracts in New Technology & Engineering	ProQuest
Materials Research Database	ProQuest
Science Citation Index Expanded (Web of Science)	Web of Science
Social Sciences Citation Index (Web of Science)	Web of Science
Directory of Open Access Journals (DOAJ)	DOAJ
OneFile (GALE)	GALE
SpringerLink	Springer
Taylor & Francis Online – Journals	Taylor & Francis
Emerald Insight	Emerald Insight

Source: Developed by the authors (2020) using data collected on the CAPES portal, access on July/24/2020

The researches in the related databases were carried out, restricting the period of publications to the last 5 years, since this is a technologically new topic, as well as focusing on filtering articles published in peer-reviewed journals to obtain scientifically reliable information. As a result, 4,144 articles were obtained.

Considering that the topic is very broad, involving numerous technologies, applied to different economic sectors and in different countries, 14,791 keywords were identified, however, the research was not redone because of the impossibility of extracting the most relevant ones for the study, considering that the volume of keywords reveals no preponderance among the terms used by the authors. Besides, the quantity of obtained articles from the research is considered numerically consistent to obtain the bibliographic portfolio.

3.1.2. Filter of raw articles database

The following filters were used to evaluate the raw articles database (4,087 articles):

- Alignment of titles to the proposed theme;
- Check the significance of the articles based on citations collected in Google Scholar;
- Alignment of abstracts with the proposed theme

As a product of the analysis of the titles, it was considered opportune to separate the selected ones in this phase into two alignment classes: (i) 72 articles aligned with the maturity measurement (or readiness) of companies concerning industry 4.0; and (ii) 11 articles that, even indirectly, deal with RD&I, maturity and industry 4.0.

The relevance analysis through a search on Google Scholar regarding received citations resulted in (i) 18 articles on maturity measurement, which received 90% of all citations in the evaluated set; and (ii) 6 articles that even indirectly deal with RD&I, maturity, and industry 4.0. From reading the abstracts, no article was excluded from the collection, resulting in the Primary Bibliographic Portfolio depicted in Table 3.

Table 3: Primary Bibliographic Portfolio

Primary Bibliographic Portfolio

Akdil, K. Y., Ustundag, A., & Cevikcan, E. (2018). Maturity and Readiness Model for Industry 4.0 Strategy (pp. 61–94). https://doi.org/10.1007/978-3-319-57870-5_4

Basl, J., & Doucek, P. (2019). A metamodel for evaluating enterprise readiness in the context of industry 4.0. *Information (Switzerland)*, 10(3). <https://doi.org/10.3390/info10030089>

Basl, J., & Kopp, J. (2017). Study of the Readiness of Czech Companies to the Industry 4.0. *Journal of Systems Integration*, 8(3), 40–45. <https://search.proquest.com/docview/1927971210?accountid=26540>

Canetta, L., Barni, A., & Montini, E. (2018). Development of a Digitalization Maturity Model for the Manufacturing Sector. In *2018 IEEE International Conference on Engineering, Technology and Innovation, ICE/ITMC 2018 - Proceedings*. <https://doi.org/10.1109/ICE.2018.8436292>

Castelo-Branco, I., Cruz-Jesus, F., & Oliveira, T. (2019). Assessing Industry 4.0 readiness in manufacturing: Evidence for the European Union. *Computers in Industry*, 107, 22–32. <https://doi.org/10.1016/j.compind.2019.01.007>

Cividino, S., Egidi, G., Zambon, I., & Colantoni, A. (2019). Evaluating the degree of uncertainty of research activities in Industry 4.0. *Future Internet*, 11(9). <https://doi.org/10.3390/fi11090196>

Colli, M., Madsen, O., Berger, U., Møller, C., Wæhrens, B. V., & Bockholt, M. (2018). Contextualizing the outcome of a maturity assessment for Industry 4.0. *IFAC-PapersOnLine*, 51(11), 1347–1352. <https://doi.org/10.1016/j.ifacol.2018.08.343>

Daemmrich, A. (2017). INVENTION, INNOVATION SYSTEMS, AND THE FOURTH INDUSTRIAL REVOLUTION. *Technology and Innovation*, 18(4), 257–265.

<https://doi.org/http://dx.doi.org/10.21300/18.4.2017.257>

De Carolis, A., Macchi, M., Negri, E., & Terzi, S. (2017). A maturity model for assessing the digital readiness of manufacturing companies. *IFIP Advances in Information and Communication Technology*. https://doi.org/10.1007/978-3-319-66923-6_2

De Carolis, A., Macchi, M., Kulvatunyou, B., Brundage, M. P., & Terzi, S. (2017). Maturity Models and Tools for Enabling Smart Manufacturing Systems: Comparison and Reflections for Future Developments. In *IFIP Advances in Information and Communication Technology* (Vol. 517, pp. 23–35). Springer New York LLC. https://doi.org/10.1007/978-3-319-72905-3_3

Erro-Garcés, A. (2019). Industry 4.0: defining the research agenda. *Benchmarking*. <https://doi.org/10.1108/BIJ-12-2018-0444>

Gökalp, E., Şener, U., & Eren, P. E. (2017). Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. In *Communications in Computer and Information Science* (Vol. 770, pp. 128–142). Springer Verlag. https://doi.org/10.1007/978-3-319-67383-7_10

Jung, K., Kulvatunyou, B., Choi, S., & Brundage, M. P. (2016). An overview of a smart manufacturing system readiness assessment. (N. I., V. O., R. J.M., G. R.F., S. M.T., K. D., & von C. G., Eds.). National Institute of Standards and Technology (NIST), Gaithersburg, MD, United States: Springer New York LLC. https://doi.org/10.1007/978-3-319-51133-7_83

Kosacka-Olejnik, M., & Pitakaso, R. (2019). INDUSTRY 4.0: STATE OF THE ART AND RESEARCH IMPLICATIONS. *LOGFORUM*, 15(4), 475–485. <https://doi.org/10.17270/J.LOG.2019.363>

Kotarba, M. (2017). Measuring Digitalization - Key Metrics. *Foundations of Management*, 9(1), 123–138. <https://doi.org/http://dx.doi.org/10.1515/fman-2017-0010>

Lee, J., Jun, S., Chang, T.-W., & Park, J. (2017). A smartness assessment framework for smart factories using analytic network process. *Sustainability (Switzerland)*, 9(5). <https://doi.org/10.3390/su9050794>

Rajnai, Z., & Kocsis, I. (2018). Assessing industry 4.0 readiness of enterprises. In *SAMI 2018 - IEEE 16th World Symposium on Applied Machine Intelligence and Informatics Dedicated to the Memory of Pioneer of Robotics Antal (Tony) K. Bejczy, Proceedings* (Vol. 2018-Febru, pp. 225–230). <https://doi.org/10.1109/SAMI.2018.8324844>

Rocha, C. F., Mamédio, D. F., & Quandt, C. O. (2019). Startups and the innovation ecosystem in Industry 4.0. *Technology Analysis and Strategic Management*, 31(12), 1474–1487. <https://doi.org/10.1080/09537325.2019.1628938>

Schagerl, M., Jodlbauer, H., & Brunner, M. (2016). Readiness model for industry 4.0 - The path to digital transformation. *Productivity Management*, 21(4), 40–42. <https://www.scopus.com/inward/record.uri?eid=2-s2.0-84987715150&partnerID=40&md5=cdbc5875e8162a9b1c0a1522e734b50b>

Schuh, G., Anderl, R., Dumitrescu, R., Krüger, A., & ten Hompel, M. (2020). Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies – UPDATE 2020. <https://en.acatech.de/publication/industrie-4-0-maturity-index-update-2020/>. Access 14 July 2020.

Schumacher, A., Erol, S., & Sihni, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. In *Procedia CIRP* (Vol. 52, pp. 161–166). <https://doi.org/10.1016/j.procir.2016.07.040>

Schumacher, A., Nemeth, T., & Sihni, W. (2019). Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. In *Procedia CIRP* (Vol. 79, pp. 409–414). Elsevier B.V. <https://doi.org/10.1016/j.procir.2019.02.110>

Shpak, N., Odrekhiivskiy, M., Doroshkevych, K., & Sroka, W. (2019). Simulation of innovative systems under industry 4.0 conditions. *Social Sciences*, 8(7). <https://doi.org/10.3390/SOCSCI8070202>

Zaoui, F., & Souissi, N. (2020). A triaxial model for the digital maturity diagnosis. *International Journal of Advanced Trends in Computer Science and Engineering*, 9(1), 433–439. <https://doi.org/10.5267/j.msl.2019.6.015>

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

Afonso et al. (2012) further say that, as the significance of recently published articles can be affected by the analysis of citations, it is still necessary to verify the adequacy of publications made in the last two years. Under this criterion, 3 articles were added to the list (table 4).

Table 4: Articles added to the Primary Bibliographic Portfolio

New Selected Articles (published in the last two years)

Lucato, W. C., Pacchini, A. P. T., Facchini, F., & Mummolo, G. (2019). Model to evaluate the Industry 4.0 readiness degree in Industrial Companies. *IFAC-PapersOnLine*, 52(13), 1808–1813. <https://doi.org/10.1016/j.ifacol.2019.11.464>

Santos, R. C., & Martinho, J. L. (2019). An Industry 4.0 maturity model proposal. *Journal of Manufacturing Technology Management*. <https://doi.org/10.1108/JMTM-09-2018-0284>

Kohnová, L., & Papula, J. (2020). WHO drives innovation activities? Evidence from innovative European countries. In *Proceedings of the 15th European Conference on Management, Leadership and Governance, ECMLG 2019* (pp. 227–236). <https://doi.org/10.34190/MLG.19.500>

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

3.2. Bibliometry

Based on the selection of the 27 articles, a bibliometric analysis of the set will be carried out, which, according to Pimenta et al. (2010), it is a technique that, through the use of quantitative and statistical evaluations, can measure and understand the evolution of scientific productions. This understanding is corroborated by Afonso et al. (2012) and Ensslin et al. (2015) that carry bibliometric analysis out on the Primary Bibliographic Portfolio in 3 stages: (i) relevance of journals; (ii) relevance of the authors; and (iii) most used keywords.

3.2.1. Relevance of journals

The Bibliographic Portfolio formed before the selection of articles by citation relevance was composed of 83 articles published in 56 journals, 2 of which proved to be the most relevant, totaling 3 publications each in the portfolio: Lecture Notes in Mechanical Engineering and IFAC-PapersOnLine. From the references of these articles, 211 journals and events were identified, of which only those with the greatest relevance (published the article in the bibliographic portfolio and/or published referenced article) will be graphically presented (Fig. 3).

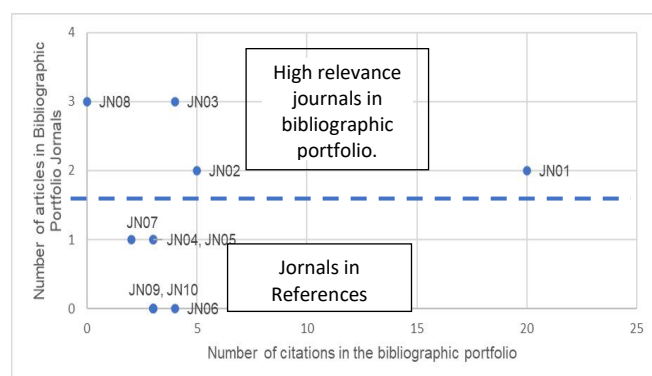


Fig. 3: Representativeness of the main journals in the bibliographic portfolio and their references

It appears that the journal *Procedia CIRP* (JN01) is considered of high relevance in bibliographic references. Standing out with the high relevance status in the bibliographic portfolio are the online *IFAC-Papers* (JN03) and *Lecture Notes in Mechanical Engineering* (JN08).

Table 5: Journals codes

Code	Journal	Code	Journal
JN01	<i>Procedia CIRP</i>	JN06	<i>MIS Quarterly</i>
JN02	<i>Computers in Industry</i>	JN07	<i>Industrial Management & Data Systems</i>
JN03	<i>IFAC - PapersOnLine</i>	JN08	<i>Lecture Notes in Mechanical Engineering</i>
JN04	<i>International Journal Product. Res</i>	JN09	<i>Business & Information Systems Engineering</i>
JN05	<i>Manufacturing letters</i>	JN10	<i>Procedia Computer Science</i>

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

The scientific impact of the 10 journals was also verified under the CiteScore metrics, which is obtained by adding the citations of a journal in a given year with those received in the last 3 years, divided by the sum of the same citations from the last 3 years; and the SJR (SCImago Journal Rank), which measures the prestige of a journal through the article citation link (ELSEVIER 2020). The results are shown in Table 6, in which it is possible to verify that the most relevant journals in terms of presence

and citations in the bibliographic portfolio are not the highlighted ones on the Citescore and SJR indicators.

Table 6: Greatest impact Journals and Citescore and SJR relevance indicators.

Journals	Quantity of articles in Bibliographic Portfolio	Quantity of citations (Portfolio)	CiteScore indicator	SJR indicator
<i>Procedia CIRP</i>	2	20	3,6	0,728
<i>Computers in Industry</i>	2	5	10	1,007
<i>MIS Quarterly</i>	0	4	11	4,531
<i>IFAC - PapersOnLine</i>	3	4	1,6	0,332
<i>International Journal Product. Res</i>	1	3	7,6	1,776
<i>Business & Information Systems Engineering</i>	0	3	7,6	1,306
<i>Manufacturing letters</i>	1	3	4,6	0,855
<i>Procedia Computer Science</i>	0	3	2,5	0,342
<i>Industrial Management & Data Systems</i>	1	2	9,1	2,084
<i>Lecture Notes in Mechanical Engineering</i>	3	0	0,5	0,165

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

Checking the works of the best-placed journals in the raw articles database indicators, it was not possible to identify texts that are aligned with the theme for inclusion in the bibliographic portfolio, which remained the same.

3.2.2. Scientific relevance of articles

The articles' scientific relevance in the bibliographic portfolio was measured based on the number of citations

consulted on Google Scholar and their relationship to the main author's number of citations in the references (Fig. 4).

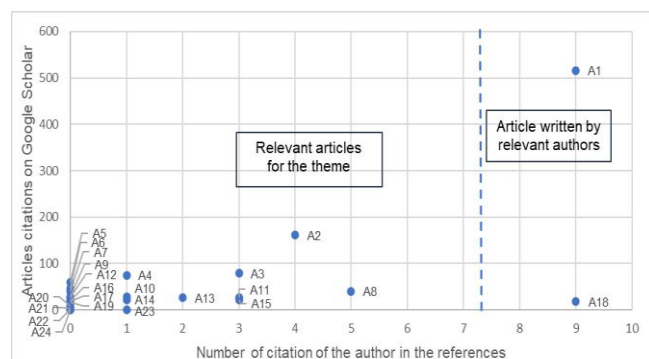


Fig. 4: Articles and their authors in the bibliographic portfolio

The articles references coded in Fig. 4 are shown in Table 7:

Table 7: Codes of bibliographic portfolio articles.

Article	Code	Article	Code
Schumacher et al. 2016	A1	De Carolis et al. 2017-b	A15
Schuh et al.2020.	A2	Basl, and Doucek 2019	A16
De Carolis, et al. 2017-a	A3	Basl and Kopp 2017	A17
Gökalp, E.et al. 2017.	A4	Schumacher et al. 2019.	A18
Castelo-Branco et al. 2019.	A5	Daemmrich 2019.	A19
Akdil et al. 2018.	A6	Erro-Garcés 2019.	A20
Kotarba 2017.	A7	Shpak et al. 2019.	A21
Jung et al. 2016	A8	Cividino et al. 2019.	A22
Colli, et al. 2018.	A9	Kosacka-Olejnik and Pitakaso 2019.	A22 b
Schagerl et al. 2016.	A10	Rocha et al. 2019.	A22 c
Lee et al. 2017.	A11	Lucato et al. 2019.	A23
Canetta et al. 2018.	A12	Santos and Martinho 2019.	A24 a
Zaoui, and Souissi 2020.	A13	Kohnová and Papula 2020.	A24 b

Rajnai and Koc

A14

sis 2018.

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

3.2.3. Authors Relevance Level

The authors' relevance is given by the number of articles within the bibliographic portfolio and within its references (Ensslin et al. 2015). The bibliographic portfolio includes 74 authors, of which Schumacher, A. and De Carolis, A. account for two articles each. In the bibliographic references, there are 225 authors of works cited in the bibliographic portfolio articles, of which Schumacher, A. is found in 9 references, and also represents the highlight in this axis (Fig. 5).

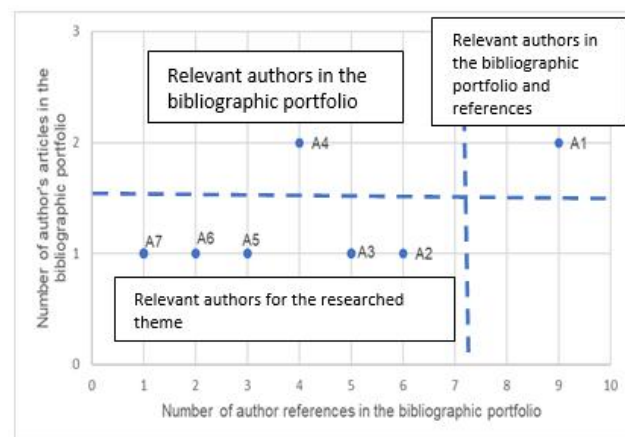


Fig. 5: Most relevant articles in the bibliographic portfolio by author

Due to the number of authors in the portfolio, it is impossible to represent them all graphically, and those shown in Fig. 5 are coded according to Table 8.

Table 8: Codes of the most relevant authors in the bibliographic portfolio

Authors	Codes	Authors	Codes
Schumacher, A.	A1	Jodlbauer, H	A6a
Schuh, G.	A2	Cruz-Jesus, F.	A6b
Jung, K.	A3a	Anderl, R.	A7a
Erol, S.	A3b	Facchini, F.	A7b
Macchi, M.	A3	Nemeth T	A7c
De Carolis, A.	A4	Oliveira, T.	A7d
Lee, J.	A5a	Rajnai, Z.	A7e

Zaoui, F.	A5b	Lucato, W.C.	A7f
		Madsen O.	A7g

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

In addition to the authors listed in the bibliographic portfolio, it was evident in this research that publications made by entities that study the industry evolution have works that are also well-referenced, which are not found in the consulted journals. They are (table 9):

Table 9: Articles produced by institutions referenced in the Bibliographic Portfolio

Entity	Title	Quantity of references on bibliographic portfolio
Pricewaterhouse Coopers (PwC)	The Industry 4.0/Digital Operations Self Assessment	3
	Industry 4.0: Building the digital enterprise	4
McKinsey & Company	Industry 4.0 after the Initial Hype	4
	Industry 4.0: How to navigate digitalization of the manufacturing sector	3

Source: Developed by the authors (2020), based on ProKnow-C methodology (Ensslin et al. 2015).

IV. ANALYSIS OF THE BIBLIOGRAPHIC PORTFOLIO

The bibliographic portfolio obtained using ProKnow-C methodology can be divided into three distinct classes within the proposed theme, namely:

- i) Industry 4.0 maturity models: the first 18 articles in table 3 and the first 2 articles in table 4;
- ii) RD&I related to the technologies implementation involving industry 4.0 systems: the last 6 articles in table 3 and the last article in table 4; and
- iii) publications by representative entities that have studied industry 4.0 and that are not available in journals: table 9.

Considering that maturity models are the first stage for the roadmap towards the implementation of technologies linked to the concept of smart manufacturing (Zaoui and Souissi 2020, De Carolis et al. 2017), they have greater relevance in the bibliographic portfolio, resulting in a greater scientific volume of this part of the theme.

Maturity indicates whether something is complete, perfect, or ready, that is, maturity indicators are used to identify the current status within a development process, and readiness indicators give information prior to maturity, however, both are used to measure industry 4.0 metrics as synonyms (Schumacher et al. 2016), thus, several widely used indicators were developed, exemplified by the Technological Readiness Level (TRL), which measures technological maturity from a commercial point of view (innovation) or the Manufacturing Readiness Level (MRL), which indicates the technological maturity of a production process, and it is not possible, through them, to make a broad diagnosis of industry 4.0 (Jung et al. 2016).

Thus, Schumacher et al. (2016), identified 62 control variables scattered over 9 dimensions represented on a radar graph, with 5 levels in each item measured by answering a questionnaire whose result was obtained by specific software to reach to a graphic outcome. The calculation of the dimensions result also considers a system of each variable relevance within the concept of industry 4.0 to obtain a weighted average.

In the study performed by De Carolis et al. (2017), maturity in digital transformation is measured in 4 dimensions and 5 variables, however, there is no case study demonstrating the developed model.

Since quantitative studies have not been found in the literature to identify industry 4.0 implementation level in countries or companies, Castelo-Branco et al. (2019) used data published by Eurostat regarding digitization indicators in the European industry. Through factor analysis method, two dimensions were reached: infrastructure in 4.0 and maturity in Big Data, both expressed through 9 control indicators.

Based on a detailed steps flow for defining the maturity measurement model, Schumacher et al. (2019) developed a model with 8 dimensions evaluated in 65 measurement variables using questionnaires structured by four levels of maturity. If filled in with maximum maturity grades 3 or 4, the method requires the participant to inform an example that supports the given grade to gain accuracy in collecting information. The final value of each analyzed variable corresponds to the average of the responses and that of the analyzed dimension is the result of the weighted average, considering each variable importance. The results are also displayed on a radar chart by the authors.

From table 10 presenting the models examples it is shown that:

i) Schumacher et al. (2016) and Schumacher et al. (2019), in both works, presented a complex system of metrics, including variables that cover a large part of the processes and people involved in the digital transformation of a company, and in the article presented in 2019, the axes and variables gained greater scope (Fig. 6 and Fig. 7);

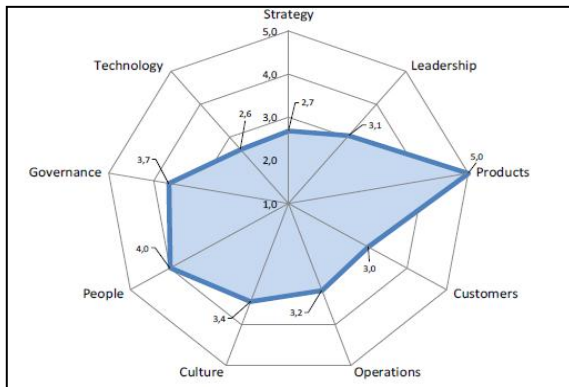


Fig. 6: Maturity model developed by Schumacher et al. (2016).

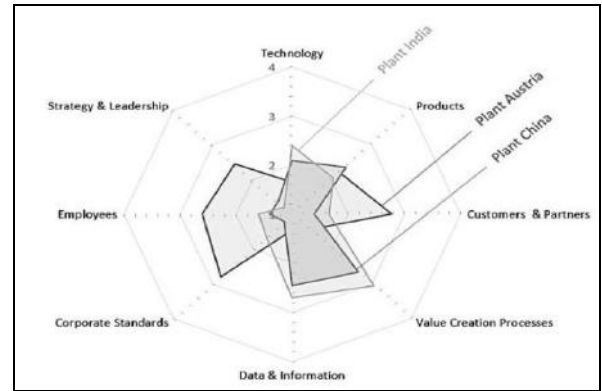


Fig. 7: Comparison of maturity using the model developed by Schumacher et al. (2019)

ii) the model developed by Castelo-Branco et al. (2019) resulted in information that relates European countries to each other, based on data provided by Eurostat (Fig. 8), with no conclusion on the application in a manufacturing plant;

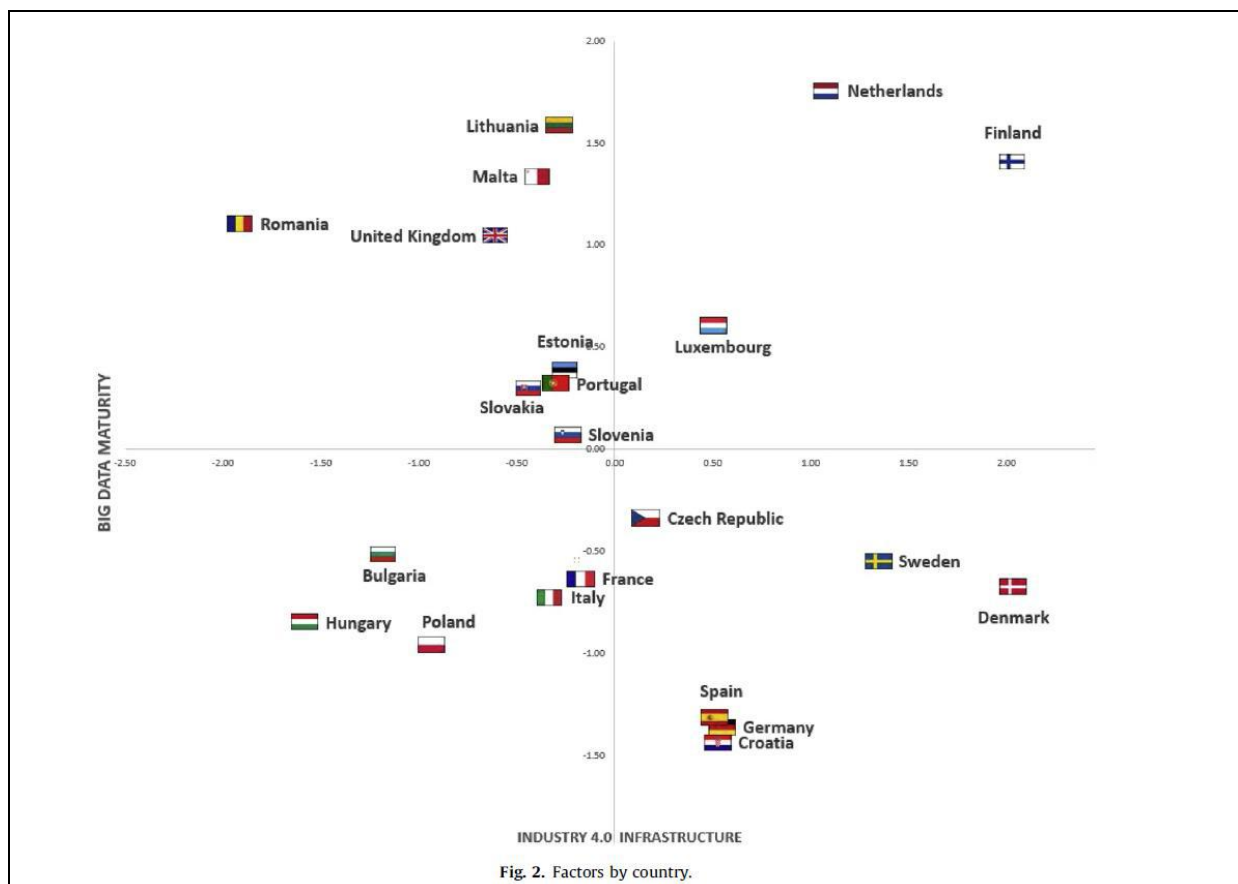


Fig. 2. Factors by country.

Fig. 8: Result of the model developed by Castelo-Branco et al. (2019)

Table 10: Examples of maturity models

ARTICLE	DIMENSIONS/AXES	VARIABLES	LEVELS
SCHUMACHER; EROL; SIHN (2016)	1- Strategy	1.1-Implementation of industry 4.0 roadmap	5 levels for each variable
	2- Leadership	1.2- Availability of resources	
	3- Customers	1.3- Adaptation to business modes	
	4- Products	...	
	5- Operations	2.1- Will of leaders	
	6- Culture	2.2 - Management skills	
	7- People	2.3- General coordination in industry 4.0	
	8- Governance	...	
	9- Technology	3.1- Use of customer data	
		3.2- Sales Digitalization	
		3.3- Customer digital competence	
		...	
		4.1- Individualization of products	
		4.2- Digitization of products	
		...	
		5.1- Processes decentralization	
		5.2- Models and simulation	
		5.3- Interdisciplinarity	
		...	
		6.1- Information sharing	
		6.2- Open-innovation program	
		6.3- ICT value in the company	
		...	
		7.1- ICT skills	
		7.2- People's receptivity to new technologies	
		7.3- Employee autonomy	
		...	
		8.1- Employment regulations for industry 4.0	
		8.2- Adherence to technology standards	
		8.3- Protection of intellectual property	
		...	
		9.1- Existence of modern ICT	
		9.2- Use and mobile devices	
		9.3- Communication	
		...	
SCHUMACHER;	1- Technology	1.1- Information sharing technology	4 levels for each

NEMETH; SIHNA (2019)	2- Products	1.2-Use of technologies in the cloud	variable
	3- Customers and partners	1.3- Mobile devices on the factory floor	
	4- Value creation processes	...	
	5. Data and information	1.8- 3D printing	
	6- Corporate standards	1.9- Use of robots	
	7- Employees	2.1- Individualization of products	
	8- Strategy and leadership	2.2- Flexibility of product characteristics	
		2.3- Collection of information on the product use	
		...	
		3.1- Receptivity to new technologies	
		3.2- Competence in ICT	
		3.3- Contact with digital client	
		3.4- Customer integration in product development	
		...	
		4.1- Automation in the value creation process	
		4.2- Autonomous machine lines	
		4.3- Sharing information between machines	
		..	
		4.8- Human-robot collaboration	
		5.1- Digital information processes	
		5.2- Data collection Automation	
		5.3- Analysis of collected data	
		...	
		5.4- Software simulation of future scenarios	
		6.1- Monitoring of the industry 4.0realization	
		6.2- Technology standards	
		6.3- Recruitment for industry 4.0	
		...	
		6.6- Increased cybersecurity	
		7.1- Receptivity to new technologies	
		7.2- Competencies in TIC	
		...	
		8.1- Strategy for industry 4.0 implantation	
		8.2- Centralized control of activities related to industry 4.0	
		8.3- Financial resources	
		...	

DE CAROLIS; TERZI; MACCHI (2017)	1- Process	1- Design and engineering	5 levels for each variable
	2- Monitoring and control	2- Production management	
	3- Technology	3- Quality management	
	4- Organization	4- Maintenance management	
		5- Logistics management	
CASTELO-BRANCO; CRUZ-JESUS; OLIVEIRA (2019)	1- Infrastructure in Industry 4.0	1- Mobile internet connection to access work applications	The analysis was performed based on data provided by Eurostat.
	2- Maturity in Big Data	2- Maximum contracted internet connection is at least 100 Mbps	
		3- Companies with ERP to share information between different functional areas;	
		4- Companies whose processes are automatically linked to the systems of suppliers and customers	
		5- Companies sending only B2B paper orders	
		6- Purchase cloud processing for internal company processing	
		7-Analyze big data from any source	
		8- Analyzes big data by internal systems and sensors	
		9- Analyze geolocation big data from mobile devices	

Source: Developed by the authors (2020), based on Castelo-Branco et al. (2019), Schumacher et al. (2016), Schumacher et al. (2019) e De Carolis et al. (2017)

It appears that there are different models for measuring maturity, and it is common among all mentioned here that they carry out a cross-sectional assessment in more than one dimension, not only measuring the level of application of digital technologies but include, for instance, training employees, available resources for investments, and strategies. Thus, the results are usually expressed in several axes and not just by a single value, which is comprehensible in the consideration that the transition to industry 4.0 involves irreversible changes in machines, systems, and their relationship with humans (Ercan and Samet 2020).

As for the articles in item “b” above, they appear as the least relevant (identified in table 7 and represented in graph 2 in codes A19, A20, A21, A22 and A24) of the bibliographic portfolio, however, they are important for the theme, as they make it clear that, in the case of the fourth industrial revolution, as well as the first to third revolutions, industry 4.0 demands an innovation system (Schpak et al. 2019) with a transversal impact on value

chains, having differential when compared with other industrial revolutions the aim of reducing the barriers between inventors and markets through the digitalization of trade (Daemmrch 2017), thus the structuring of innovation in the context of industry 4.0 with different actors for a new ecosystem creation is the basis for value chains generation supported by the end-to-end integration with a high scale of relationship between the participants who, through innovative technological solutions, will be able to ever, monitor and digitally simulate physical conditions through digital twins with the objective to make decisions in an assertive manner, reducing risks of activities. (Cividino et al. 2019, Lim et al. 2020).

It is important to note, however, that the public policy established by IL that obliges beneficiary companies to invest in RD&I defines a unique scenario, not being explored in any of the selected articles even in an analogous way, evidencing a scientific gap regarding the relationship of the maturity of industries concerning industry 4.0 metrics with investments made in RD&I.

V. FINAL CONSIDERATIONS / CONCLUSION

The development of industrial processes to implement technologies applied to the concepts of industry 4.0 has been seen by entrepreneurs, academia, and government as a way to maintain the competitiveness of national or local production, thus, strategies must be adopted so that physical systems are digitized with intelligence and connectivity gains.

However, establishing an advancement of industrial parks plan has as a prerequisite the knowledge of the maturity level at which companies are to establish adequate public policies (government), training plans and qualification of human resources (academy), and investments (entrepreneurs).

Bearing in mind that public policies to encourage research, development, and innovation are part of the recent history of the Manaus Industrial Pole and that these three pillars support the implementation of industry 4.0, this work used a systemic process to select the main scientific literature, here called the bibliographic portfolio, available on industry 4.0 maturity measurement models linked to the RD&I.

Obtaining the bibliographic portfolio occurred along with two of the four stages defined in the ProKnow-C methodology, which are (i) the definition of the raw articles database and (ii) the realization of filters (Fig. 2).

Then, 12 keywords were selected, distributed in 4 research axes, which, inserted in the journal database maintained by CAPES, made it possible to select 8 journal bases that returned as result a set of 4,144 articles, from which 57 duplications were filtered, reaching the raw articles database, subsequently submitted to the alignment filters of the title, abstract, number of citations and the full text, resulting in the bibliographic portfolio, composed of 27 articles.

The following step was the portfolio bibliometry by which the relevance of journals, articles, and authors was analyzed resulting in:

a) journals: the most relevant journal in terms of occurrence (2 articles) and citations (20) in the bibliographic portfolio was *Procedia CIRP*, however, the biggest impact on Citescore and JSR was the *MIS Quarterly* (table 6). This result did not cause any change in the defined portfolio, since, in the re-analysis of titles and abstracts, the articles did not adhere to the theme;

b) articles: with the number of citations as an indicator, the most relevant article in the bibliographic portfolio is the “A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing

Enterprises.”, whose authors are Schumacher, A et al. W., with 516 citations indicated by Google Scholar, who are also the most-cited authors in the references of the bibliographic portfolio with 9 citations, a fact that also includes the article entitled “Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises.”;

c) authors: with 2 works in the bibliographic portfolio, the main authors of the most relevant articles are Schumacher, A. and De Carolis, A. As for the authors that appear in the references of the bibliographic portfolio, Schumacher, A. is also the most relevant.

RD&I is treated in the bibliographic portfolio in less significant articles from the point of view of the bibliometric study, however, they bring relevant content regarding the need to generate an innovation ecosystem capable of sustaining the development of the industry for the digital transformation.

Finally, the bibliographic portfolio resulting from the applied ProKnow-C methodology showed a gap as to the intersection between the companies' maturity in industry 4.0 metrics and their obligation or willingness to invest in RD&I, which is the scenario brought up by the theme of this work, as well, it is evident the need for studies that can translate the unique condition generated by public policies that, within the imposition and investments, allows the application of resources in smart manufacturing.

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